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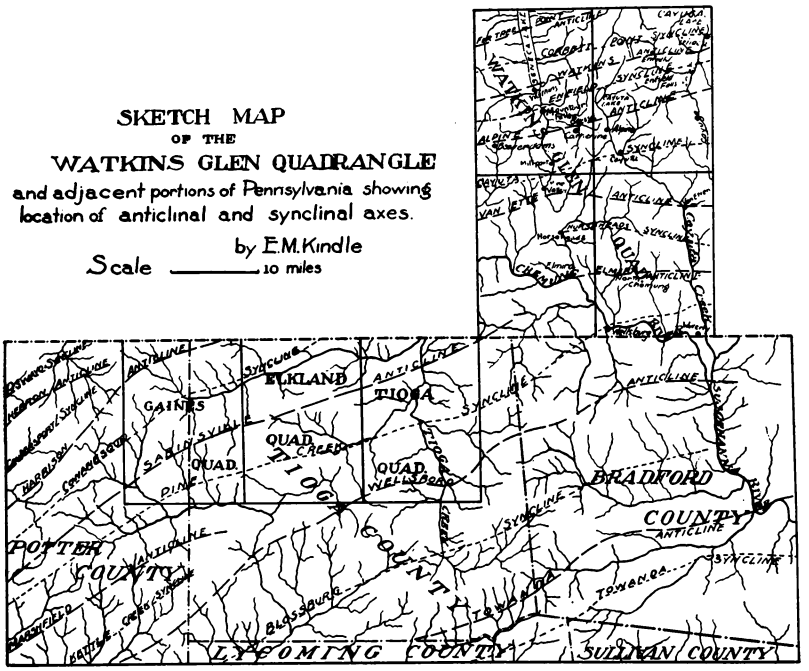
A SERIES OF GENTLE FOLDS ON THE BORDER OF THE APPALACHIAN SYSTEM.[1]

THE conclusions of this paper have been reached in the study of the Watkins Glen quadrangle, New York. This quadrangle comprises the four fifteen-minute quadrangles known as the Watkins, Ithaca, Elmira, and Waverly quadrangles. Extending from the Pennsylvania state line to the Seneca and Cayuga Lake valleys, it includes the southern portion of each. This area lies immediately north of the region of the Appalachian folds. The surface rocks of the quadrangle are the shales and sandstones of the Chemung, Portage, and Genesee formations. The rock strata over much of the area vary so little from the horizontal position that the dip can usually be recognized only by the very careful use of the clinometer or the level. Dips high enough to be conspicuous, and ranging from 8 to 55°, have been noted occasionally in various parts of the quadrangle, but these high dips have in nearly all cases been found to be associated with small local anticlines or faults, extending frequently only a few rods and possessing only local interest. With these higher dips the present paper is not concerned; but the interpretation of the more obscure dips ranging usually from 1 to 3 or 4° will be attempted.

A careful study of the low dips characterizing the rocks over the major part of the quadrangle has shown them to have an important structural significance. They have been found to represent a series of low, approximately parallel, anticlinal folds, having the same general direction as the great mountain folds immediately south of them in Bradford county, Pennsylvania.

[1] Published by permission of the director of the U. S. Geological Survey.

Very gentle dips ranging from ½ to 5°, but rising in a few instances to 10° or more, characterize these folds. Although very low, they belong to anticlinal folds, which are very persistent. Some of them have been traced entirely across the quadrangle. Five of these folds, separated by a corresponding number of synclines, have been recognized. Beginning at the north, the folds will be designated by the



following names: the Fir Tree Point anticline, the Watkins anticline, the Alpine anticline, the Van Etten anticline, and the Elmira anticline. The position of these minor folds with reference to the nearest Allegheny folds is shown by the accompanying sketch map.[1]

Fir Tree Point anticline.—This fold has a width along Lake Seneca of five and one-half miles. The axis crosses the lake at Fir Tree Point, two and a half miles south of the northern edge of the quadrangle, bearing a little north of east. Nearly continuous

[1] The location of the Pennsylvania folds shown by the map is based upon maps published in the *Pennsylvania State Geological Reports* and in *Folio No. 93*, U. S. Geological Survey.

exposures of the rock in the lake shore cliffs on each side of the anticlinal axis, as far as the synclinal axes limiting the arch make it possible to measure accurately the total height of the arch by noting the thickness of the successive beds as they rise above the lake level. Measured in this way, the crest of the anticline is found to rise about 115 feet above the troughs of the synclines on each side. This anticline therefore brings to view 115 feet of strata which are below lake-level at the northern edge of the quadrangle. This includes about 75 feet of typical Portage sandstones and shales, and some forty feet of black and dark gray shales which represent the transition between the Portage and the Genesee, corresponding to the Middlesex shales of Clarke and Luther.

The north dips terminate at the synclinal axis crossing the lake on the east side at the edge of the quadrangle north of Peach Orchard and just north of Glenora on the west side. The axis of the Corbett's Point syncline to the south of this fold crosses the lake just north of Corbett's and Cottage Points, three miles south of the anticlinal axis. The amount of the north and south declinations of this fold along Seneca Lake are practically the same, but its axis is a half-mile nearer to the synclinal axis on the north than it is to the synclinal axis on the south, so that the inclination of the north limb is somewhat greater than that of the south limb.

It is very probable that the anticline crossing Lake Cayuga in the vicinity of Shurger Point, which has a maximum elevation of 235 feet on the east side and 160 feet on the west side,[1] is the northeastern continuation of the Fir Tree Point anticline, but the continuity of the two has not been verified by a study of the dips in intervening territory. Along Lake Cayuga, south of Shurger's Point south dips continue until the synclinal axis at Ithaca is reached, the rate of dip being about 110 feet per mile.

Watkin's anticline.—Six miles south of Fir Tree Point a second, but much lower, fold crosses the south end of Lake Seneca. Its axis crosses the lake just north of Watkins, six miles south of Fir Tree Point. Continuing eastward by northeast, it crosses the Cayuga Inlet valley in the southern edge of Ithaca. The maximum height of the fold above the syncline on the north is about 35 feet. A band

[1] *American Journal of Science*, Vol. XXVI (1883), p. 304.

of heavy-bedded sandstone outcropping at the foot of the cliffs just below the entrance to Watkins Glen affords a convenient datum plane from which to determine the height of the Watkins fold. This is the only band of sandstone exceeding 10 or 12 inches in thickness in this part of the section, and it is easily followed from its outcrop north of Salt Point, where its base is only a few inches above lake level to Watkins, where it reaches its maximum elevation of 30 feet above the lake in a ravine just north of the village.

This sandstone band dips below lake-level about 500 yards north of Salt Point. From the point where it disappears to the axis of the syncline the north dip does not exceed 10 feet, so that the total rise of the fold above the Corbett Point syncline is probably between 35 and 40 feet. On the east side of the lake the maximum elevation of the fold, which is about 10 to 12 feet less than on the west side, is attained at the quarry just north of Excelsior Glen. From this point, where the band of massive sandstone mentioned above is 20 feet above lake-level, the dip is very gentle to the north, the sandstone band reaching lake-level at the north side of "Painted Rocks," about one mile north of Excelsior Glen. South of Watkins the Watkins Glen sandstone is seen at the base of the quarry half a mile below town. A short distance south of this point it dips below the level of the marsh.

At Ithaca the very gentle north dips of this fold are seen along the west side of the Inlet valley from the south edge of town nearly to the lake. The much heavier south dips appear in South Hill. The south dips of this fold both at Ithaca and Watkins greatly exceed the north dips. The synclinal axis between this fold and the next on the south passes a little north of Montour Falls and Lake Cayuta, through the village of Enfield and out of the quadrangle east of the upper dam in Buttermilk Creek.

Alpine anticline.—The strongest fold in the quadrangle is the next one south of the Watkins fold and running parallel with it. The axis of this fold enters the quadrangle nearly west of Beaverdams. Passing a little north of Beaverdams and south of Moreland, it crosses Catherine Creek valley about five miles south of the head of Seneca Lake, and Cayuta Creek one mile north of Alpine. The axis crosses Cantor Creek one and a half miles north of Pony Hollow; passing

between Newfield and Stratton, it continues northeasterly to the edge of the quadrangle. Continuing this axis into the Dryden quadrangle, in the same direction which it follows in the Ithaca quadrangle, it joins the anticline which in the vicinity of Brookton is represented by southerly dips of 5 to 6°.

The northerly dips of the Alpine anticline usually vary between 1 and 2°. North dips as high as 3° have, however, been observed in the quarry in Odessa, and along Cayuta Creek one mile south of Cayuta Lake. The south dips are much stronger than the north dips, and vary from 3 to 10°. Northeast of Chambers south and southeasterly dips of from 3 to 8° are seen. In the ravine east of Alpine half a mile the dips range from 8 to 10° in a southeasterly direction. Just west of West Danby the south dips vary from 3 to 6°. The average south dip for this fold is probably 3½ or 4°.

It will be noted that the total south dip in this quadrangle of the rocks to the north of the axis of the Alpine anticline is very small. The much greater inclination of the beds to the south of this axis over those to the north of it makes the effective south dip along the southern edge of this fold much greater than elsewhere in the quadrangle, and explains the abrupt appearance of the Chemung in all of the hills on the south flank of this fold.

The synclinal axis to the south of this fold enters the region about a mile south of the northwest corner of the Elmira quadrangle. Passing northeasterly through Millport, it crosses Cayuta Creek just south of Cayuta and leaves the quadrangle about one mile north of the Chemung-Tompkins county line.

Van Etten anticline.—The axis of this fold crosses Cayuta Creek at Van Etten. Bearing a little to the north of west, it crosses Catherine Creek about a half-mile south of Pine Valley, thence, trending a little south of west, it passes just north of Catherine, and probably leaves the quadrangle to the west of Quackenbush Hill. The north and south dips of this fold may be seen along nearly all of the streams which it crosses. The dips of the north limb of the fold are particularly well displayed in the outcrops along Dry Run, Langford Creek, and Cayuta Creek. The dips of the south limb of the fold may be seen along Dean Creek, Cayuta Creek, Baker Creek, and a number of other small streams to the south of the axis, varying usually from 2 to 3°.

The synclinal axis south of the Van Etten fold crosses Cayuta Creek apparently about two and three-quarters miles north of Reniff. Its position has been recognized just east of Horseheads, but west of this point the complexity of the dips renders the determination of its course uncertain.

The Elmira anticline.—The axis of the southernmost anticlinal fold in the quadrangle runs eastward from about the abrupt southerly bend of the Chemung River east of Elmira; passing south of North Chemung and just north of Chemung Centre, it crosses Cayuta Creek just north of Lockwood. At Lockwood the north limb of the anticlinal has flattened until the dip cannot be detected by the clinometer or hand-level, but there is probably a very small north dip for two and one-half or three miles up the valley to the point where the south dips of the Van Etten fold cease. In the western half of the Waverly quadrangle the north dips are pronounced along Baldwin Creek northeast of North Chemung and its tributaries to the west of North Chemung. The north dip at the quarries east and north of Elmira, which averages about 2°, may be observed nearly to Horseheads. The south dips of this fold along the east side of the Chemung River range from 3 to 5° south or southeast. The south dips east of this may be seen along nearly every south-flowing stream to the eastern edge of the Waverly quadrangle. The course of the fold west of Elmira is not entirely clear. Sherwood recognized the Elmira anticline as a continuation of a Pennsylvania fold and states that "it crosses the Chemung River a little below Elmira."[1] Sherwood states that he "has seen no dips beyond Elmira and Horseheads."[2] Heavy southwest dips for two miles along the river west of the city and also north of the summit of Hawley Hill indicate the probability, as suggested by Mr. M. L. Fuller, that the axis bends to the north, west of Elmira, passing between Hawley and Hawes Hills. Thence, bending southward, it probably joins the Sabinsville anticline near the southwestern corner of the quadrangle.

The syncline to the south of the Elmira anticline is well defined in the southeastern part of the Waverly quadrangle. The axis crosses Cayuta Creek about three miles north of Waverly. Passing westward between Shoemaker Mountain and Narrow Hill, it crosses

[1] *Report G*, Pennsylvania Geological Survey, p. 95. [2] *Ibid.*, p. 96.

the Chemung River to the north of Wellsburg. Apparently it bears sharply to the southwest near this point and joins the Pine Creek syncline of Pennsylvania. While the connection between the Pine Creek and Narrow Hill synclines has not been clearly established, the rather abrupt eastward bend of the former, which follows, if they are continuous, is in harmony with the sudden change in the trend of the Wellsburg anticline and the Blossburg syncline on the south from northeast to east.

It appears certain that the comparatively insignificant structural features which have been described are of the same age and origin as the great open folds of the northern Alleghenies. In the quadrangle cornering with the Watkins Glen quadrangle on the southwest are folds whose arches, if restored, would rise 2,500 feet above their troughs.[1] Less than twenty miles to the south of the Watkins Glen quadrangle another great fold shows a crest of similar or greater elevation. From theoretical considerations it would appear improbable that the effects of the epirogenic forces which have developed structures of such magnitude should terminate abruptly at the northern edge of the highly folded belt. Instead of abrupt change from highly folded to monoclinal or nearly horizontal structure, we find the mountain flexures subsiding gradually into the low, gentle swells which have been described. This may be illustrated by a comparison of the maximum dips exhibited by the anticlinal folds encountered between South Mountain in Bradford county, Pennsylvania, and the southern end of Lake Seneca. Eighteen miles south of the Watkins Glen quadrangle runs the axis of the Towanda anticline between two synclinal mountain ridges—Mount Pisgah and South Mountain. Dips of 70° or more have been observed on the south side of this anticline, but the average dip for the belt of maximum inclination is approximately 40°. The dips of the north limb of this fold are very much lower than the south dips. The writer, although familiar with the region, has not observed any dips which will exceed 20°, and the dips in the zone of maximum inclination will probably not average more than 15°. It is noteworthy that the great excess of the south dip over the north dip of this fold is a characteristic common to nearly all folds of the Watkins Glen quadrangle.

[1] *Folio No. 93*, U. S. Geological Survey, p. 5.

The next anticlinal axis north of the Towanda anticline approaches to within about six miles of the southern edge of the Watkins Glen quadrangle. This anticline, which is known as the Wellsburg anticline, does not differ greatly, as developed in Bradford county, from the Alpine anticline of the Watkins Glen quadrangle in the magnitude of the dips, which seldom exceed 5° in Bradford county. The latter has, however, less than half the width of the Wellsburg anticline, which accounts for the failure of the Alpine anticline to develop synclinal mountain ridges, such as those associated with the Wellsburg fold. In the Elmira fold, which is the next fold north of the Wellsburg syncline, the maximum dips have dropped to 2° for the north limb and about 3 or 4° for the south limb. The Watkins, fold, which is about fifteen miles north of the Elmira fold, may be cited as showing the smallest dips of any fold in the quadrangle, the maximum amounting to 1° or less.

It follows as a result of the anticlinal structure which has been described that the total southerly declination of the beds of the quadrangle, amounting to several hundred feet, is not the result of a regular or approximately uniform rate of dip to the south per mile, as has been generally assumed.[1] On the contrary, the rocks rise toward the south on the north side of each of the axes described. The dip of the south limb of the fold is, however, as stated above, usually greater than the north dip. In the case of the Alpine anticline the south dip is very much greater than the north dip, the result being that the total of the south dips in the quadrangle considerably exceeds the north dips, and that any given horizon at the south side of the quadrangle is several hundred feet lower than at the north side.

Between the south end of Lake Cayuga and Newfield the north and south dips about balance each other, the beds of a given horizon being at nearly the same level at these two points. The same is

[1] Since completing the field work on which this paper is based, the writer's attention has been called to a paper by Professor H. S. WILLIAMS (*Proceedings of the American Association for the Advancement of Science*, Vol. XXXI (1882), p. 412), which gives a brief description of folds corresponding to the eastern portion of some of those herein described. Hall observed the north dips between Elmira and Horseheads in 1839, and states that the rocks rise "southward from Horseheads to the Chemung River." (*Third Annual Report, Fourth Federal District*, p. 323.)

true of the dips of the beds in the Seneca Lake valley—similar horizons lying as high or higher at the axis of the anticlinal fold two miles south of Montour Falls as at Cottage Point eight miles north. On crossing the axis of the Alpine anticline, however, a south dip ranging from 3 to 8° brings the beds very rapidly toward sea-level.

The various maps of the New York State Survey, which cover portions or the whole of this region, have evidently been constructed on the supposition of an approximately uniform southerly dip in the region about the southern ends of the Seneca and Cayuga Lake basins. As a consequence, the Chemung-Portage parting, as shown on these maps, involves an inaccuracy of several miles in many places. In the "Finger Lakes Sheet," and the revised state map published in 1901, the northern limit of the Chemung between the Seneca and Cayuga basins is drawn about ten miles south of its actual northern limit, while the Portage has been found by the writer above drainage several miles south of the southern limit shown by the map.

The conclusions stated above have, as shown, been reached through a study of the stratigraphy, but supplementary paleontologic work has been found to confirm them throughout. The writer has found typical Chemung fossils at the northern edge of the Watkins quadrangle, about ten miles north of the northern limit of the Chemung, as given by the New York state map for that meridian. Due east of Ithaca, *Spirifer disjunctus* has been found in the higher beds, which have heretofore been supposed to belong to a Portage terrane and which lie about seven miles north of the Portage-Chemung boundary for that region, according to the New York state map.

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